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Radiological Assessment of Radioactive Waste Disposal Areas at Oak Ridge National Laboratory

Vol. 3—Technical Background Information for the ORNL Environmental and Safety Report

T. W. Oakes
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RADIOLOGICAL ASSESSMENT OF RADIOACTIVE WASTE DISPOSAL AREAS AT OAK RIDGE NATIONAL LABORATORY

Vol. 3 — Technical Background Information for the ORNL Environmental and Safety Report

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Industrial Safety and Applied Health Physics Division

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2	A Description of the Aquatic Ecology of White Oak Creek Watershed and the Clinch River below Melton Hill Dam	ORNL/TM-7509/V2	J. M. Loar, J. A. Solomon, and G. F. Cada
3	Radiological Assessment of Radioactive Waste Disposal Areas at Oak Ridge National	ORNL/TM-7962	T. W. Oakes, W. F. Ohnesorge, E. B. Wagner, and M. Y. Chaudhry
4	White Oak Lake and Dam: A Review and Status Report — 1980	ORNL-5681	T. W. Oakes, B. A. Kelly, W. F. Ohnesorge, J. S. Eldridge, J. C. Bird, K. E. Shank, and F. S. Tsakeres

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ABSTRACT

Thermoluminescent dosimeters (TLDs) were used to determine dose equivalent rates in the ORNL solid waste disposal areas. The dosimeters were exchanged and read approximately quarterly during 1979 and 1980. The data were reviewed to detect trends in dose equivalent rates, but no trends were detected other than increased radiation levels in some areas due to the lowering of White Oak Lake. The rates at the disposal site were compared with TLD readings taken in areas on the DOE reservation perimeter, as well as in remote areas that represent natural background for East Tennessee.

INTRODUCTION

Terrestrial, cosmic, and internal radiation are the principal sources of man's natural radiation environment. In the United States, the mean dose equivalent attributed to natural background radioactivity is about 80 to 200 millirems per year (0.8 to 2.0 mSv/year) (Oakley 1972). A combination of man-made radiation sources (e.g., radioactive waste disposal areas, nuclear weapons tests, nuclear reactors, and isotope production facilities) contributes less than 5 millirems per year (0.05 mSv/year) (U.S. Public Health Services 1964). Human exposure depends upon a variety of factors, including geographic location, types of building materials used in housing, and meteorological parameters such as temperature, humidity, and barometric pressure.

SOURCES OF NATURAL RADIATION

Cosmic Radiation

The two primary components of cosmic radiation or cosmic rays are galactic radiation and solar radiation. Galactic radiation, which originates beyond our solar system, contributes high energy particles thought to extend beyond 1×10^{10} GeV in energy (Korff 1964). This type of cosmic ray is composed of about 75 to 89% protons, 10 to 18% helium nuclei, and 1 to 7% nuclei with an atomic number greater than 3 (Neher 1967). Solar radiation, which originates from sun phenomena such as solar flares, consists primarily of protons and helium nuclei (Neher 1967; Lowder and Beck 1966).

Terrestrial Radiation

The earth is a significant source of human exposure to radiation. The major nuclides contributing to this terrestrial exposure are ^{40}K and nuclides in the decay chains of ^{238}U and ^{232}Th. A neutron component of cosmic rays interacts at the earth's surface and produces additional radionuclides, ^{14}C and ^{3}H for example. Other nuclides are present in rocks and soil but are considered insignificant because of their relatively low concentrations (Lowder and Solon 1956).

SOLID RADIOACTIVE WASTE DISPOSAL SITES AT ORNL

Oak Ridge National Laboratory has used six solid radioactive waste disposal areas (SRWDA's) since 1943 when it began operating. About half of the disposal sites were chosen for their convenience, with little consideration being given to geological or hydrological factors. As the volume of waste increased, sites were selected that contained Conasauga shale because of its ion-exchange properties, which would inhibit the migration of water-soluble nuclides through the soil. The six SRWDA's are shown in Fig. 1. Table 1 shows the operating status and land area used for each disposal site.

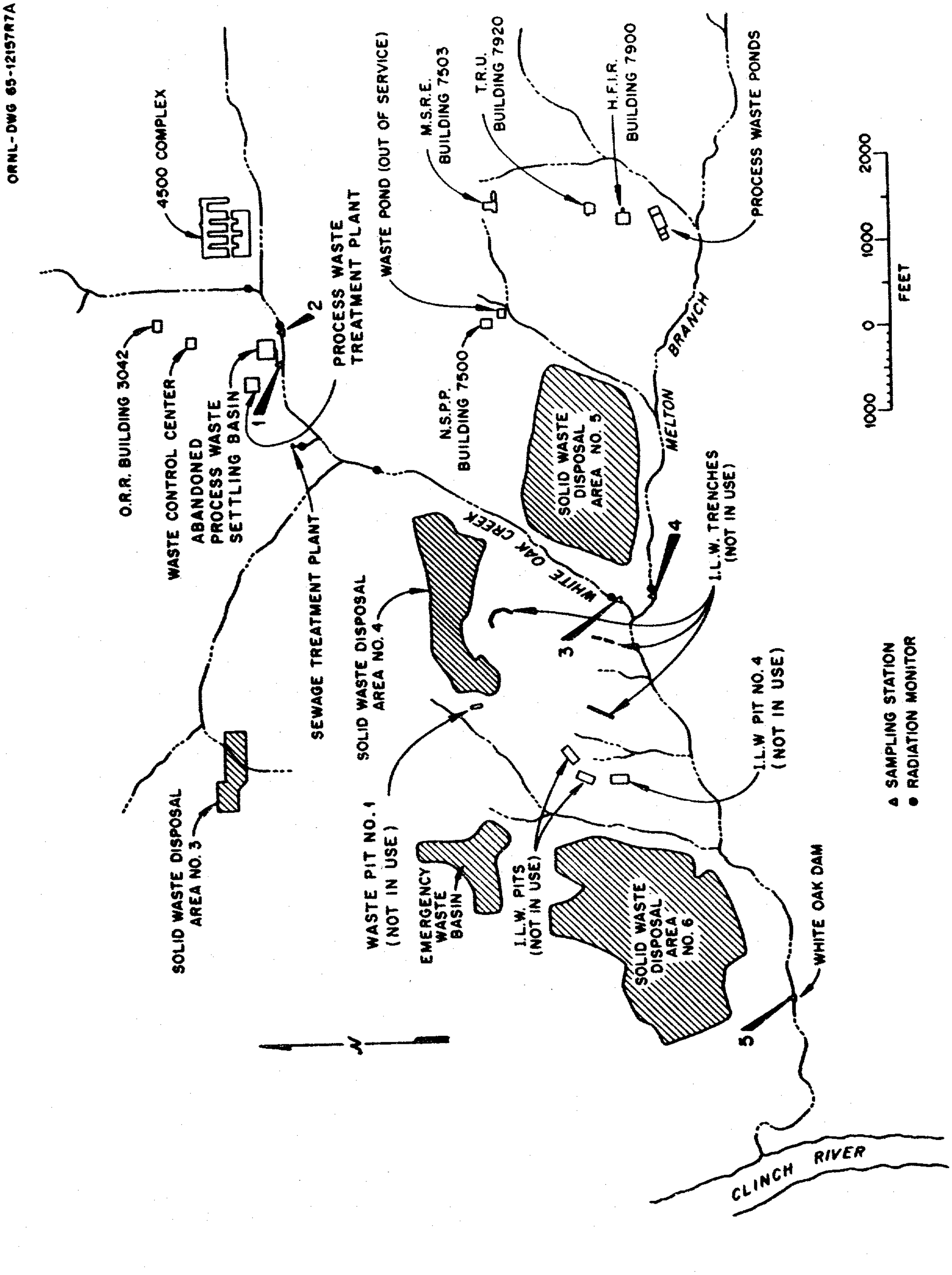

Fig. 1. Locations of solid radioactive waste disposal areas.

Table 1. Operational status of ORNL solid radioactive waste disposal areas

SRWDA[a]	Operating dates		Land used (acres)[b]
	Opening date	Closing date	
1	1943	1944	1
2	1944	1946	4
3	1946	1951	7
4	1951	1959	23
5	1959[c]		33
6	1969[c]		68

Source: Adapted from Oakes and Shank, 1979.
[a]Solid radioactive waste disposal area.
[b]One acre = 4047 m^2.
[c]Still in operation.

SRWDA No. 1

The SRWDA No. 1, with a total area of 1 acre (4047 m^2) is located at the foot of Haw Ridge, at the edge of the Laboratory complex, about 25 ft (7.4 m) south of White Oak Creek. This site was selected for its proximity to the Laboratory; waste leaching into the water system was not considered. Waste was dumped into open trenches and backfilled. There are no available records showing the quantity or kind of solid waste disposed of in these areas. Very little monitoring data are available from the SRWDA No. 1 area (Webster 1976). The area was closed in 1944 because water was found in one of the trenches.

In 1946, the site was surveyed for surface contamination, and soil samples were analyzed. The results from only two areas indicated radioactivity above background levels. In 1975, water samples from two wells and a surface seep in this area were analyzed for ^{90}Sr, ^{137}Cs, and transuranic elements. These analyses showed low concentrations of ^{90}Sr [9.4 dpm/mL (157 Bq/L)] present in one of the wells, but no detectable quantities of ^{137}Cs or transuranic elements were found (Duguid 1976).

SRWDA No. 2

The SRWDA No. 2 was operated between 1944 and 1946, and covered a total area of about 4 acres (1.62×10^4 m^2). The site is located on the lower half of a hill near the Laboratory's east entrance. The site was selected primarily because fewer personnel would be exposed during the transportation of the waste from this site (Webster 1976). Very little attention appears to have been given to environmental protection.

No available records document the quantity or kind of solid waste disposed of in this area. It has been learned that solid waste contaminated by beta or gamma activity was placed in black iron drums and buried in the trenches. Plutonium-contaminated liquid waste, which was placed in stainless steel drums and was either buried in trenches or stored without burial in a "natural ravine," eroded into the denuded slope (Webster 1976).

Because the use of the SRWDA No. 2 site was found to be incompatible with the Laboratory's long-range land-use planning, its operation was suspended in 1946. Subsequently, most of the waste buried on this site was exhumed and reburied in SRWDA No. 3. The stainless steel drums containing liquid plutonium waste were removed intact, but the black iron drums containing beta-gamma solid waste had deteriorated. Thus, the earth surrounding these drums was also removed and reburied at SRWDA No. 3. The hillside of the SRWDA No. 2 site was then bulldozed to smooth out the irregularities and was then seeded (Oakes and Shank 1977).

In August of 1977, thirteen core samples were collected at various points in the SRWDA No. 2. Water samples were also collected from the core holes. Activity levels in water samples were found to be insignificantly different from those of background samples when analyzed for ^3H, gross-alpha, and gross-beta activity. A representative portion of the homogenized whole core was used for this analysis. The average uranium and plutonium concentrations were found to be 0.47 pCi/g (0.017 Bq/g) and 0.06 pCi/g (0.002 Bq/g) respectively (Oakes and Shank 1977). The levels found in the cores are indicative of only "natural" radioactivity and weapons fallout similar to that found in other eastern Tennessee locations. For example, the average radioisotope concentration for soil samples near the perimeter of the DOE area in Oak Ridge has been found to be 0.66 pCi/g (0.024 Bq/g) of uranium and 0.04 pCi/g (0.0015 Bq/g) of plutonium (Oakes, Shank, and Easterly 1976).

The average ^{137}Cs concentration for the upper third and the entire core is 0.7 and 0.3 pCi/g (0.026 and 0.011 Bq/g) respectively. Both of these values are similar to the value of 1.0 pCi/g (0.037 Bq/g), the average value of topsoil samples collected in 1976 and 16 sites throughout eastern and central Tennessee (Oakes, Shank, and Easterly 1976). It should be noted that these soils samples are from cores several feet long and that they are being compared with topsoil samples. For ^{90}Sr, the average values for the core were $\leq$0.57 and $\leq$0.53 pCi/g ($\leq$0.021 and $\leq$0.020 Bq/g) for the upper third and the entire core respectively (Oakes, Shank, and Easterly 1976). These ^{137}Cs and ^{90}Sr activities are typical of the levels expected from fallout at the time the samples were taken.

SRWDA No. 3

The SRWDA No. 3 is about 0.6 miles (1.0 km) west of the Laboratory's west entrance. The site is a flat, forested area at the foot of Haw Ridge. Presumably, this area was chosen as a waste disposal site because of its proximity to the Laboratory, its out-of-sight location, and because the soil could be readily excavated (Webster 1976). The site became operational in 1946. Alpha-contaminated wastes were dumped in unlined trenches and covered with concrete, but the beta-gamma waste was covered with native soil.

Samples of well water from the area were analyzed in 1964 and indicated small amounts of the trivalent rare earths (TRE), ^{90}Sr, ^{89}Sr, and ^{3}H (Webster 1976). Analyses of well samples collected in 1973 indicated ^{90}Sr levels as high as 3.0 dpm/mL (50 Bq/L). Soil samples were collected and analyzed during 1978, and the results are given in Eldridge et al. (1979). The results indicated levels higher than natural soil background levels (Oakes, Shank, and Easterly 1976).

When the thermoluminescent dosimeter (TLD) study began in 1979, this area was being cleared of items that had been stored above ground. After the stored equipment and materials were removed, new top soil was brought in and the area was reseeded. Thus, SRWDA No. 3 was not included in the TLD study.

SRWDA No. 4

From 1948 to 1950, a study (Stockdale 1951) of the geology and hydrology of the Laboratory site was conducted, and it was subsequently recommended that wastes be disposed of in the Conasauga shale belt. The SRWDA No. 4 was opened in 1951 in the closest area to the Laboratory underlain by Conasauga shale. Trench orientation was variable and lacked any consistent relationship to original site topography (Webster 1976). Auger holes 1 to 2 ft (0.3 to 0.6 m) in diameter were used in this area for the disposal of higher level radioactive waste [>200 millirems/h (>2 mSv/h) at the surface]. The site was closed in 1959 and resulted in a disposal area totaling 23 acres (9.3×10^4 m^2).

A number of small seeps have developed near the rim of the terrace in the center third of the area, and others are reported to have developed in the central part of the site. In 1959 and 1960, samples from wells and streams in and near this area indicated that both groundwater and surface water were contaminated (Webster 1976). Eight of sixteen wells showed beta-gamma contamination. Water samples from two seeps indicated contamination by ^{90}Sr, ^{137}Cs, ^{95}Zr-, ^{95}Nb, ^{60}Co, and TRE. The section of White Oak Creek flowing by SRWDA No. 4 indicated radioactive contamination by ^{106}Ru, ^{90}Sr, ^{210}Po, ^{239}Pu, and TRE. In 1964, water samples were collected from six wells and one seep, and each was found to contain $^{89,90}Sr$, ^{3}H, TRE, and minor amounts of ^{106}Ru (Webster 1976). Discharges of ^{90}Sr from SRWDA No. 4 and annual precipitation are given in Table 2.

Soil samples were collected in 1973 along the south side of SRWDA No. 4. These samples contained small amounts of ^{60}Co, ^{137}Cs, and ^{90}Sr (Duguid 1976). The soil along White Oak Creek east of the area was found to have been contaminated by seepage from SRWDA No. 4 and discharges from the creek. Near this site is a contaminated floodplain area, which was once flooded by an intermediate pond. A dam was constructed in early 1944 to help create an intermediate retention pond between the Laboratory and White Oak Lake. The dam was breached in late 1944, and a small pond remained until 1950 (Duguid 1976).

Table 2. Strontium-90 discharges versus precipitation

Water year[a]	Precipitation (cm)	Total ^{90}Sr discharge (Ci)[b]
1967	154	2.7
1968	114	2.0
1969	102	2.1
1970	122	1.6
1971	123	1.2
1972	120	2.4
1973	181	1.6
1974	175	5.2
1975	147	3.2
1976	124	5.1
1977	129	2.3
1978	155	1.4
1979	169	1.7
1980	97	0.9

[a]Measurements for these years were taken from September 1 through August 31.
[b]To convert from curies (Ci) to becquerels (Bq), multiply curies by 3.7×10^{10}.

SRWDA No. 5

The SRWDA No. 5 was opened in 1959 and consisted of two sections on the hillside east of White Oak Creek and south of Haw Ridge. This area was opened because the functional capacity of SRWDA No. 4 was nearly exhausted. Initially, the same burial procedures were used at this site as had been used at the other sites; that is, alpha-contaminated waste was placed in the lower part of the area and capped with concrete, and the beta-gamma-contaminated waste was simply covered with weathered shale. This segregation procedure was discontinued sometime during the operational life of the site. Trench lengths at the site varied from <40 feet (2 m) to >50 feet (15 m). These trenches were oriented parallel to the topographic slopes (Webster 1976). Water samples were collected from several wells in 1964. The principal contaminants found were ^{90}Sr, ^{89}Sr, ^{106}Ru, ^{3}H, and TRE. Several new wells were cored and sampled. The data suggested that at the time, only minor movement of radioactivity had occurred. In 1960, samples from these wells indicated that SRWDA No. 5 was the major source of ^{3}H (Webster 1976) in White Oak Creek.

Most of the transport of radionuclides in the surface water is monitored at Sampling Station 4 on Melton Branch. Additional data are given in the section on monitoring stations. In 1974, 13 small seeps were sampled along the south edge of the area. These samples contained measurable amounts of total alpha, ^{90}Sr, ^{3}H, and ^{125}Sb. Eleven of the samples contained concentrations of ^{90}Sr ranging from 9×10^{-8} to 6.1×10^{-5} µCi/mL (3.3×10^{0} to 2.3×10^{3} Bq/L) (Duguid 1976).

SRWDA No. 6

The SRWDA No. 6 is located immediately northwest of White Oak Lake. This site totals about 70 acres (2.8×10^{5} m^{2}) and was opened in 1969. Initially, trenches were excavated to be as long as possible, but their length is now limited to about 50 ft (15 m). This restriction was set to reduce to an acceptable level the amount of water collected in the trenches (Webster 1976). Some monitoring around this area has been completed. The results indicate some movement of radioactivity, but it is too early to judge the results accurately.

Contractor's Landfill

A variety of areas have been used to dispose of debris from construction sites and noncontaminated demolition activities. The current site, which was opened in 1975, is located west of SRWDA No. 3.

THERMOLUMINESCENT DOSIMETER (TLD) DESCRIPTION AND GRADING PROCEDURE

Two $0.32 \times 0.32 \times 0.089$-cm LiF thermoluminescent dosimeters (TLDs) (TLD-100, The Harshaw Chemical Co.) with a natural isotopic composition of 7.5% ^{6}Li and 92.5% ^{7}Li were placed in a Lucite TLD ring holder and then put into polyethylene bottles containing 3 g of 6-16 mesh silica gel desiccant (Fig. 2). These polyethylene bottles were suspended 1 m above the ground in each of the burial ground areas for 3 months.

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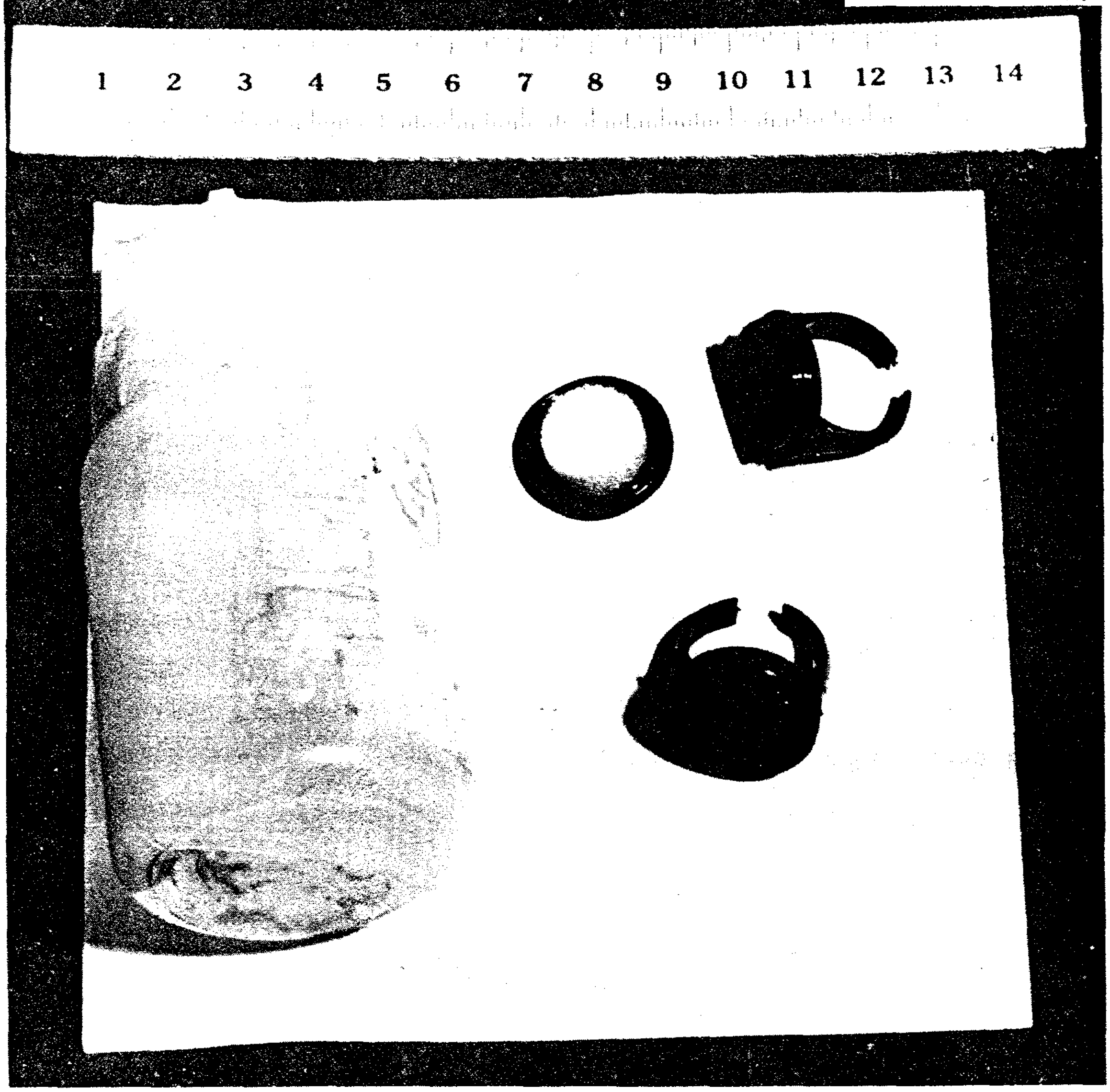

Fig. 2. Polyethylene bottle containing Lucite TLD holder and silica gel.

All TLDs were graded initially for their response per unit of exposure to a radium source. The first step in the grading procedure was to anneal the TLDs for 30 min at 400°C and then heat them for 2 h at 100°C. They were then exposed to a 102.67-mg radium source (in radioactive equilibrium) encased in 1-mm-thick Monel (alloy composition — 60% Ni, 33% Cu, 7% Fe, and a density of 8.9 g/cm^3). This cylindrical source, measuring 0.84 cm long with a 0.07-cm diameter, was calibrated with a National Bureau of Standards source. Exposure rate was calculated in millirems per hour by using the following:

$$\text{millirem/h} \cong \frac{MK}{d^2} ,$$

where

M = absolute amount of radium (mega Bq),

$K = 8600 \frac{(\text{millirem})\ (\text{cm}^2)}{(\text{h})\ (\text{mega Bq})}$ (correction factor 1-mm Monel encasement),

d = distance from source (cm).

Each TLD was then irradiated for 78 s in the Lucite TLD ring holder, positioned 13.7 cm from the source, to obtain a dose equivalent of 100 millirems (1.0 mSv). The apparatus for TLD source exposure was described previously (Becker 1973). The Lucite TLD ring holder (1 g/cm^2 thickness) afforded good geometry for exposure with a minimum of scattering. After irradiation, the TLDs were oven-tempered at 80°C for 20 min and then read in a TLD reader.

TLD Handling and Readout Procedure

Each TLD chip was handled carefully to decrease the probability of damage and, consequently, to decrease change in TLD response. Control TLDs were put into a cylindrical lead encasement [4-in. (10-cm) thick walls] to minimize background radiation contributions. At the midpoint of each 3-month period, one set of control TLDs was irradiated with 100 millirems (1.0 mSv) from the described radium source and returned to the lead shielding. These control TLDs, as well as the TLDs distributed to the field, were read the same day. The TLDs were read as soon as they were returned from the field to decrease the amount of storage time and consequent fading.

Before they were read, all TLDs returned were pretreated by oven-tempering at 80°C for 20 min. The dose equivalent rates obtained from the field TLDs were calculated as follows:

$$\left(\frac{R_{av}}{h}\right)(CF)(1000) = \text{microrems per hour}$$

where

CF = correction factor

$$= \frac{100 \text{ millirems}}{\text{irradiated control TLD (millirems) - background TLD (millirems)}} ,$$

R_{av} = average of the two TLD readout values,

h = number of hours at location,

1000 = conversion factor to obtain microrems.

RESULTS AND DISCUSSION

Results of external exposures at the perimeter and remote air monitoring (PAM and RAM) locations (Figs. 3 and 4) are given in Tables 3–6. Figure 1 shows the locations of waste disposal areas. Dosimeters were placed at the burial ground sites (Figs. 5-10) at the beginning of 1979. The locations were numbered, and the dosimeters were exchanged and read approximately quarterly for 2 years. The location of the storage trenches was not taken into consideration for dosimeter placement. Results of external radiation measurements using thermoluminescent dosimeters at ORNL solid-waste disposal grounds are presented in Tables 7–18. Table 19 gives a profile of the average exposure rate at each burial ground, over the 2-year study period.

The exposure rates at the waste storage areas are definitely higher than they are at the PAMs and the RAMs. The exposure rates at the burial ground sites (excluding SRWDA's Nos. 1 and 4) are about twice as high as are those in the areas around ORNL.

As was mentioned earlier, the exposure rates at SRWDA's Nos. 1 and 4 are somewhat higher than are the exposure rates at SRWDA's Nos. 2, 3, and 5. This may be because of the aging effect. The storage cans are deteriorating and may be releasing the radionuclides that are transported to the surface by infiltrating rainwater. At SRWDA No. 6, the leaching

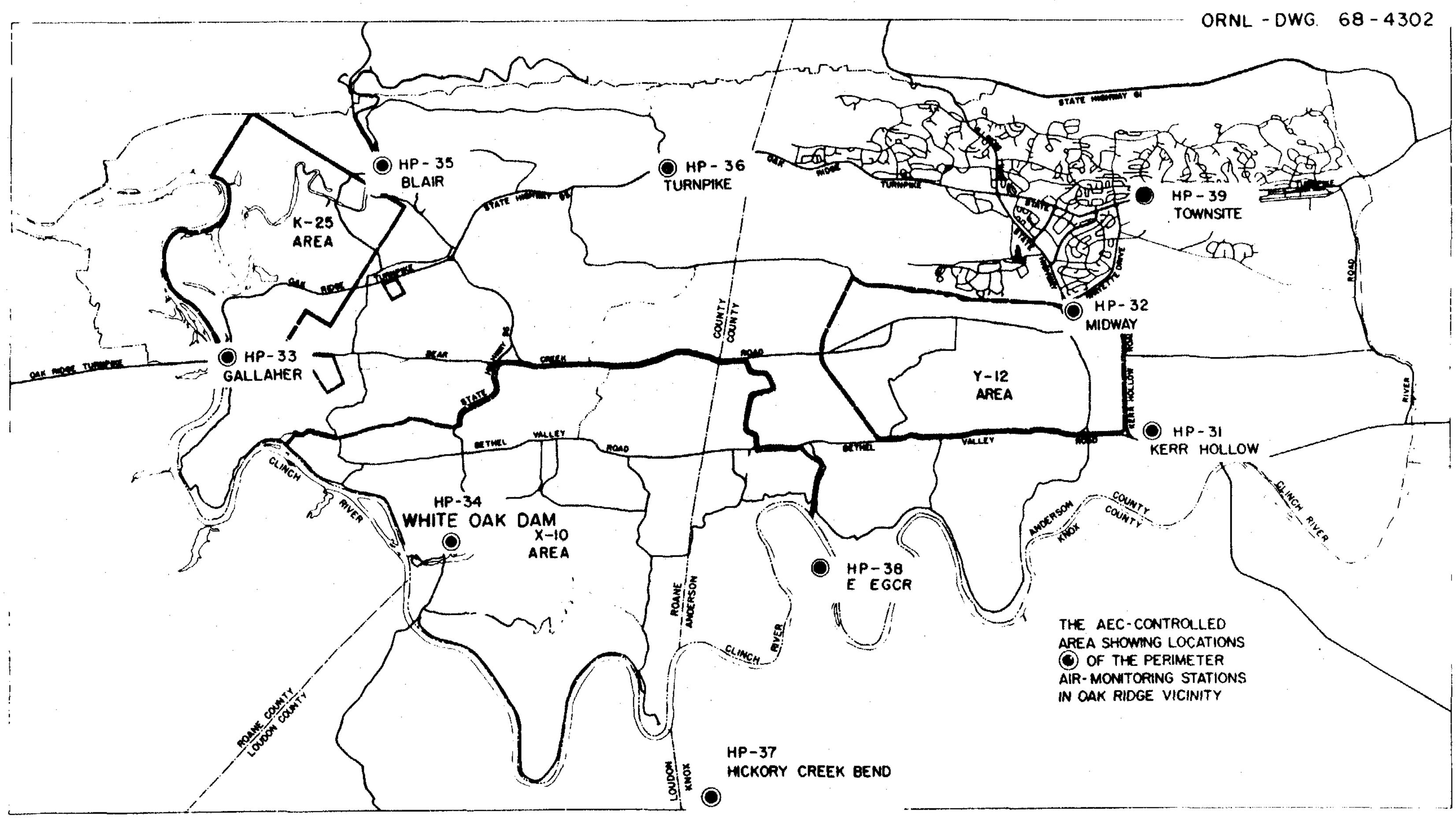

Fig. 3. Perimeter air monitoring locations.

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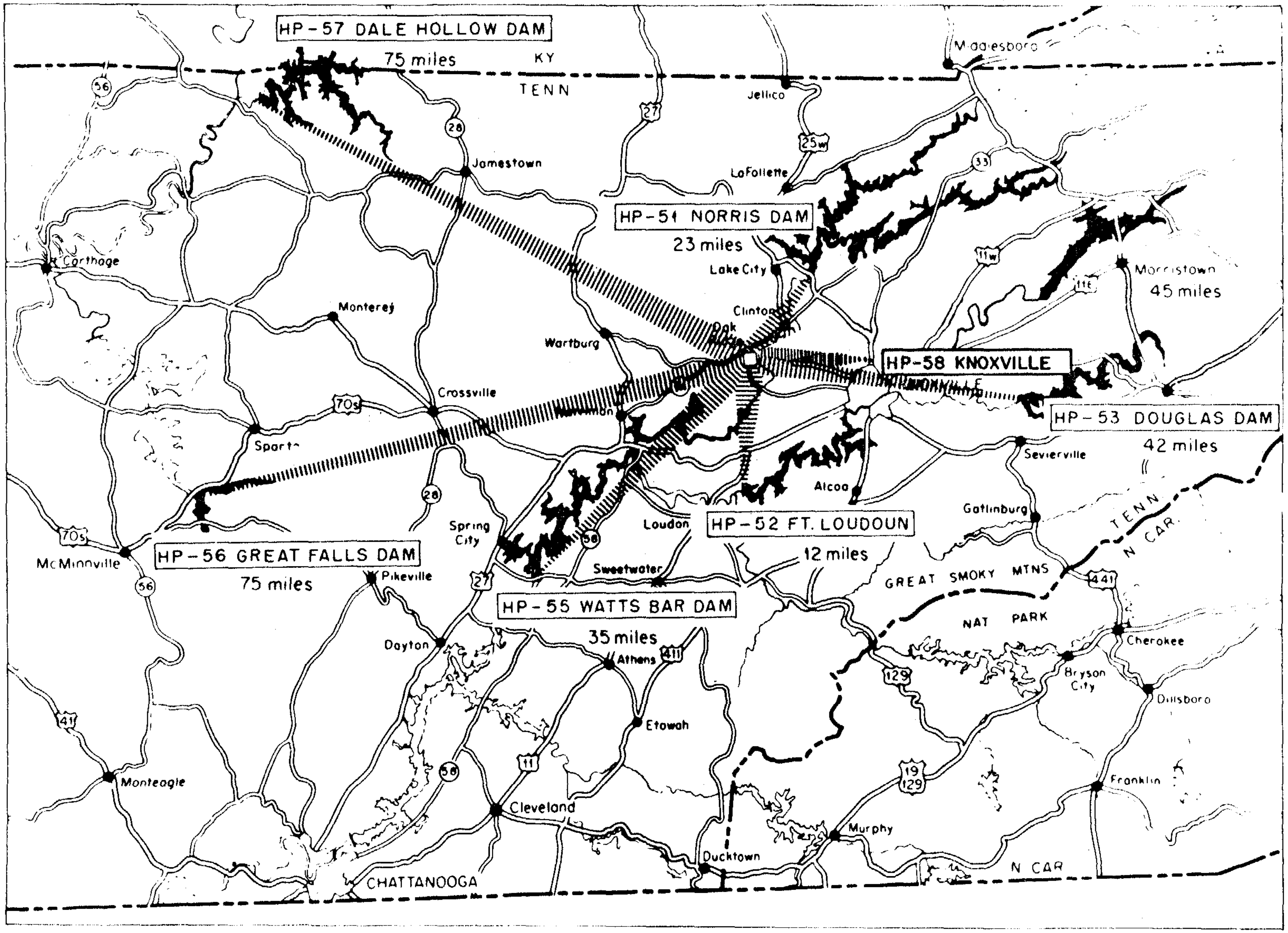

Fig. 4. Remote air monitoring locations.

Table 3. TLD 200 results at PAMs[a] for 1979

Dose equivalent rates are measured in microrems per hour[b]

TLD no.	First quarter	Second quarter	Third quarter	Fourth quarter
23	8.67	7.83	5.46	10.57
31	10.77	11.33	6.93	8.10
32	11.70	11.60	7.41	5.4
33	11.50	10.13	7.25	8.40
34	11.77	12.20	9.10	7.50
35	13.67	9.83	6.29	9.73
36	9.9	10.00	6.13	8.10
37	9.13	10.30	6.37	8.17
38	10.00	9.63	6.54	8.40
39	9.77	10.10	5.35	7.43
40	6.30	8.57	5.13	7.23
41	20.85	12.93	6.68	8.27
42	32.05	16.67	14.71	21.03
Average	12.78 ± 6.72	10.90 ± 2.22	7.19 ± 2.48	9.10 ± 3.79

[a]*PAM* refers to perimeter air monitoring locations.
[b]To convert microrems per hour to microsieverts per hour, multiply microrems per hour by 0.01.

Table 4. TLD 200 results of RAMs[a] for 1979

Dose equivalent rate measured in microrems per hour[b]

TLD no.	Dose equivalent rate: First half	Dose equivalent rate: Second half
51	5.8	5.3
52	8.2	6.01
53	8.4	2.91
54	8.1	2.80
55	6.6	5.63
56	6.0	5.95
57	13.2	7.43
58	13.2	8.73
Average	8.69 ± 2.96	5.60 ± 2.02

[a]*RAM* refers to remote air monitoring locations.
[b]To convert from microrems per hour to microsieverts per hour, multiply microrems per hour by 0.01.

Table 5. TLD 200 results of PAMs[a] for 1980

Dose equivalent rate measured in microrems per hour[b]

TLD no.	First quarter	Second quarter	Third quarter	Fourth quarter
23	6.76	6.80	3.77	5.70
31	10.13	7.07	4.80	11.0
32	12.35	7.73	6.30	13.4
33	9.50	5.70	4.47	11.33
34	18.30	14.03	8.77	22.73
35	8.67	7.10	4.1	9.27
36	7.6	8.43	4.4	9.00
37	8.37	11.10	7.03	10.25
38	8.53	7.10	7.20	9.20
39	4.47	8.33	7.43	9.10
40	5.90	6.83	4.27	7.63
41	11.27	10.67	5.98	17.50
42	23.67	16.27	8.20	9.20
Average	10.42 ± 5.25	9.01 ± 3.15	5.90 ± 1.71	11.18 ± 4.49

[a]PAM refers to perimeter air monitoring locations.

[b]To convert microrems per hour to microsieverts per hour, multiply microrems per hour by 0.01.

Table 6. Results of RAMs[a] for 1980

Dose equivalent rate measured in microrems per hour[b]

TLD no.[c]	Dose equivalent rate	
	First half	Second half
51	5.53	5.13
52	7.47	6.79
53	7.54	7.01
55	6.37	6.0
56	6.35	9.55
57	6.58	12.8
58	10.35	10.1
Average	7.17 ± 1.56	8.20 ± 2.72

[a]*RAM* refers to remote air monitoring locations.

[b]To convert from microrems per hour to microsieverts per hour, multiply microrems per hour by 0.01.

[c]*TLD* refers to thermoluminescent dosimeters.

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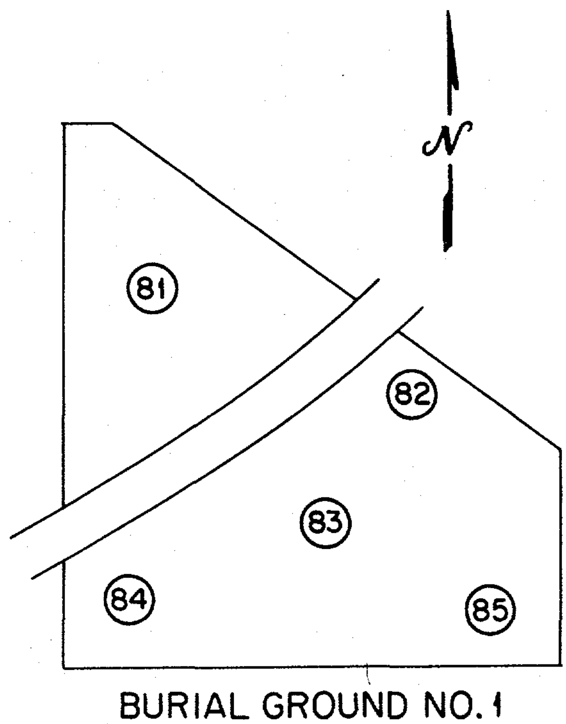

Fig. 5. Solid waste storage area No. 1.

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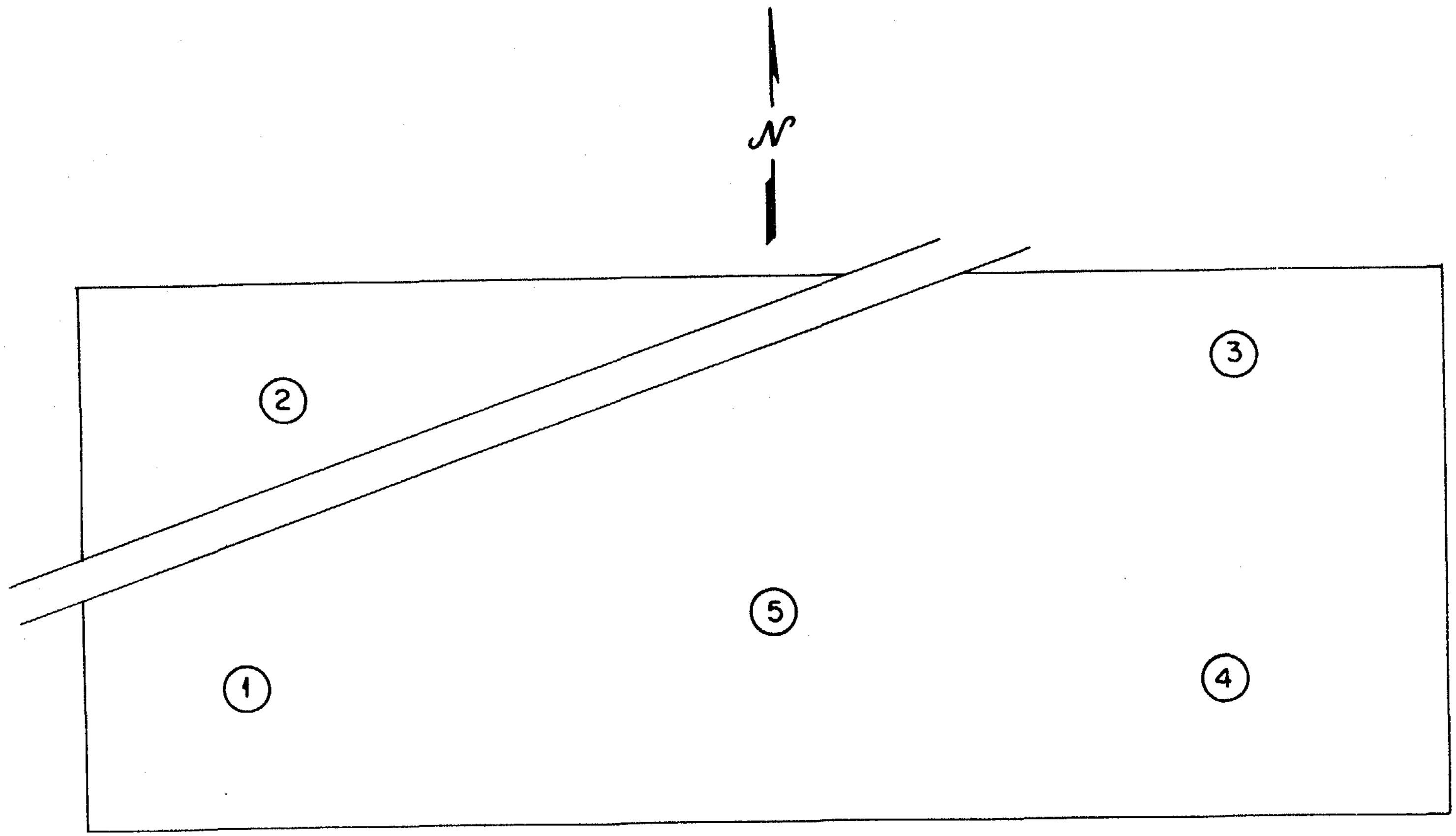

BURIAL GROUND NO. 2

Fig. 6. Solid waste storage area No. 2.

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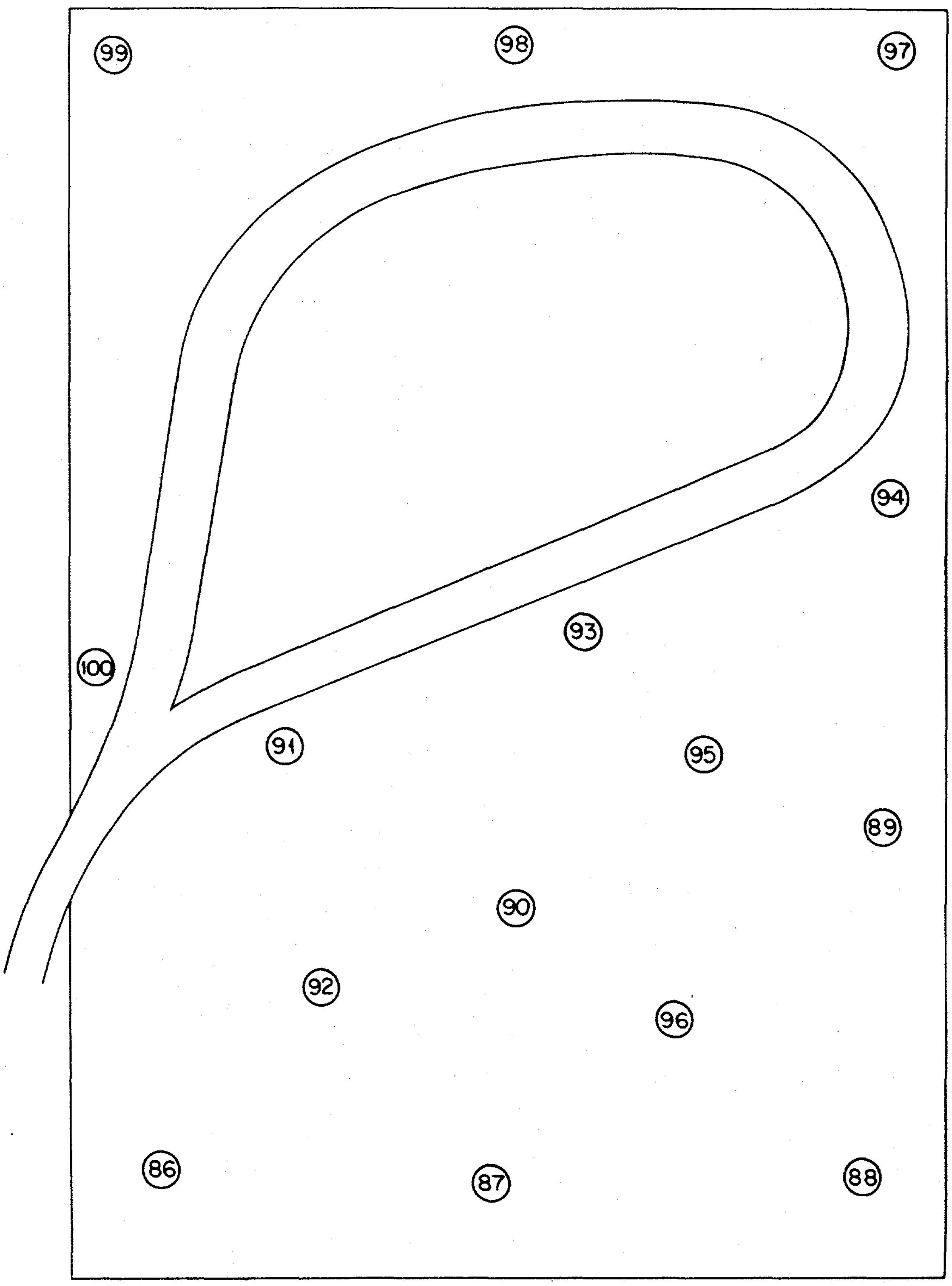
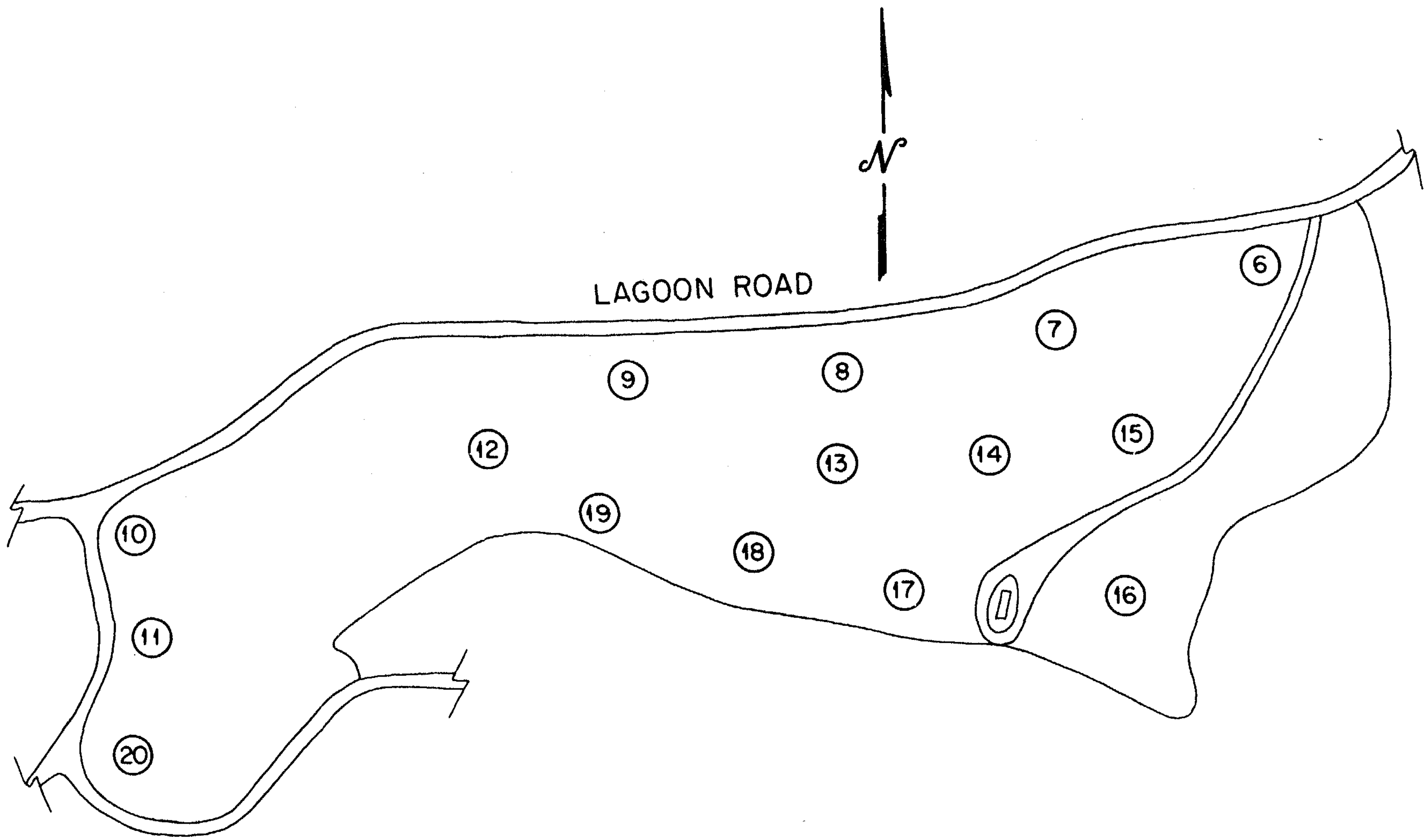


CONSTRUCTION LANDFILL

Fig. 7. Construction landfill site.

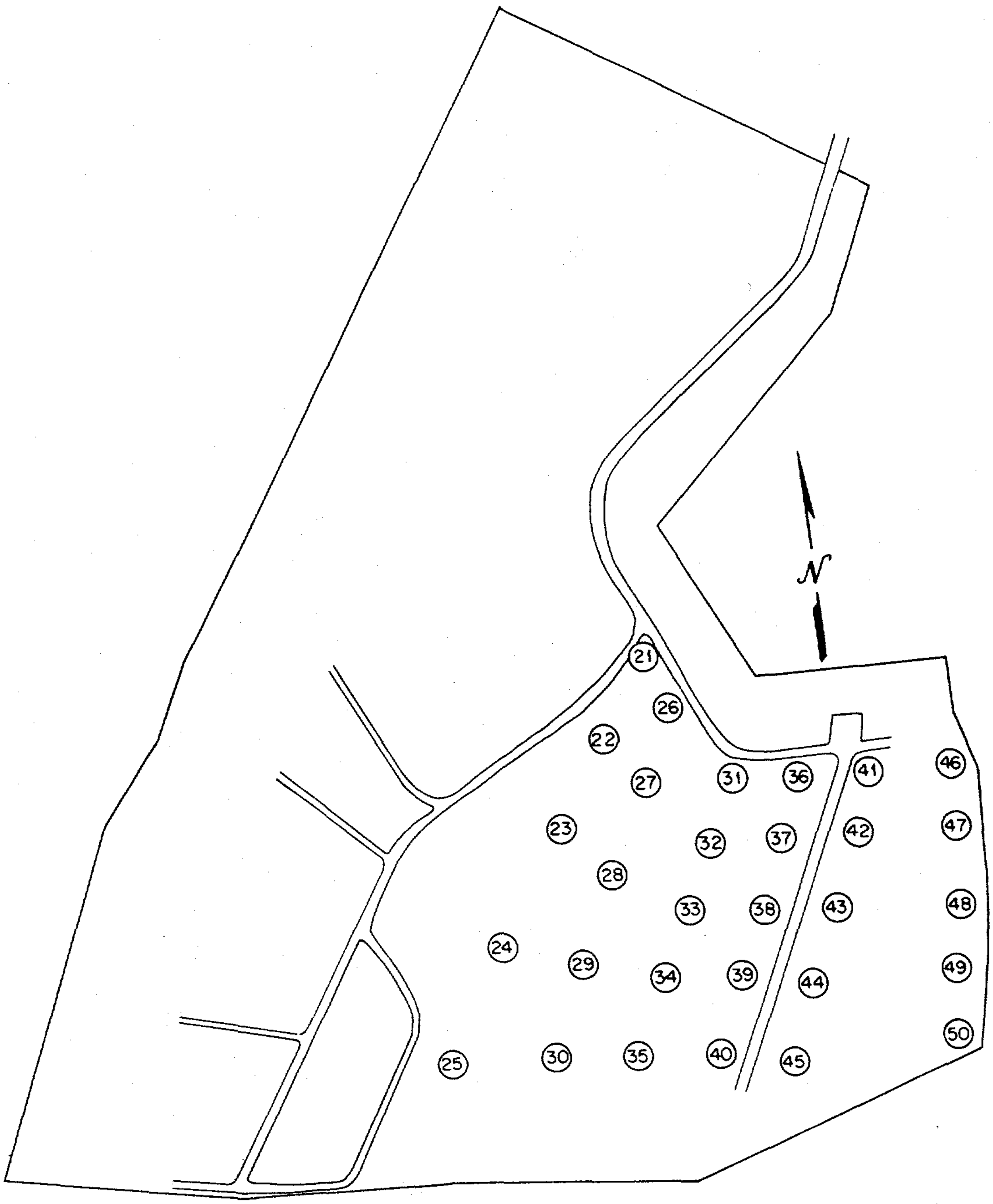
ORNL-DWG 80-8992



SOLID WASTE STORAGE AREA NO.4

Fig. 8. Solid waste storage area No. 4.

ORNL-DWG 80-8989



SOLID WASTE STORAGE AREA NO.5

Fig. 9. Solid waste storage area No. 5.

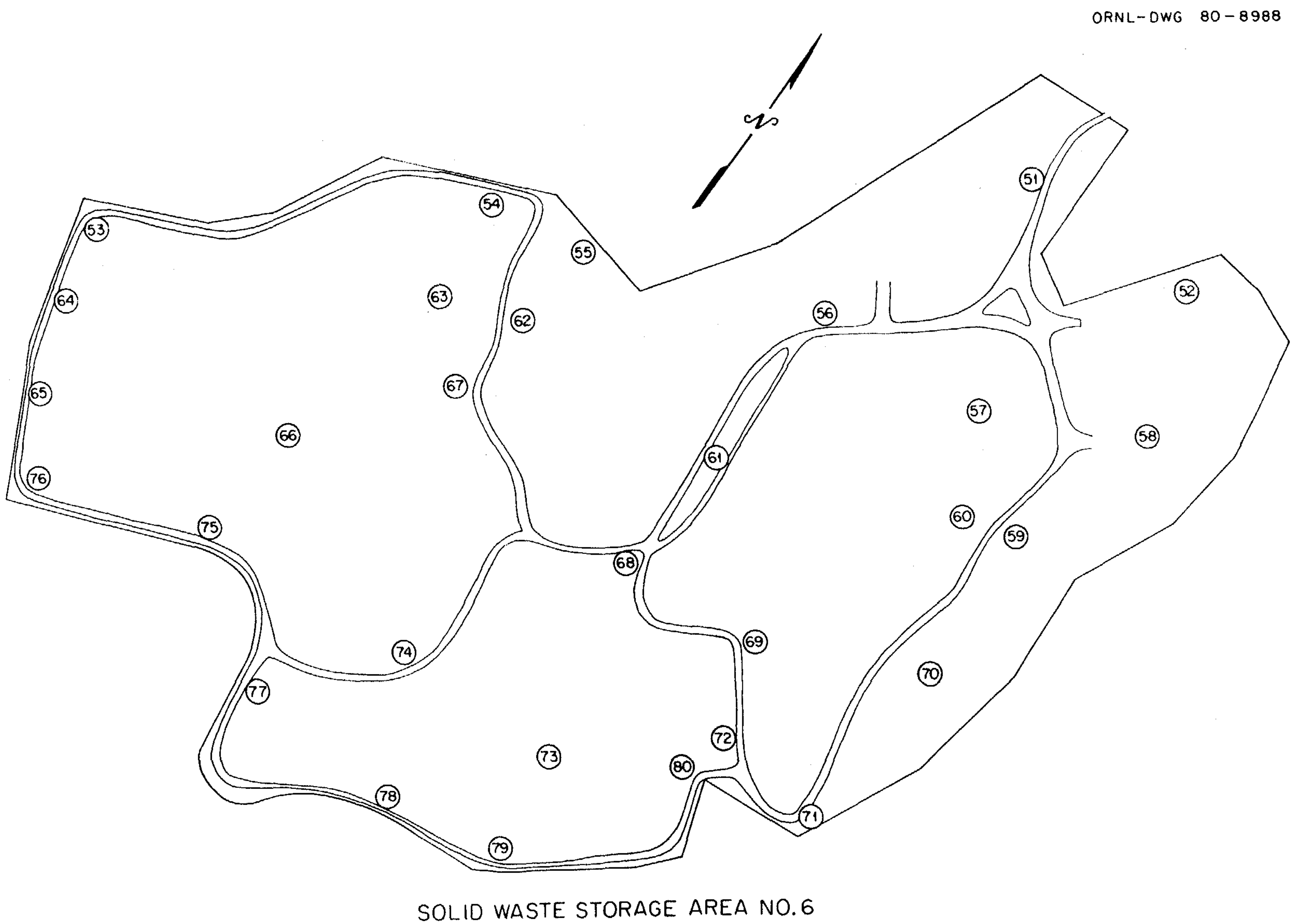


Fig. 10. Solid waste storage area No. 6.

Table 7. Results of TLD readings for SRWDA No. 1, 1979

TLD no.	Dose equivalent rate measured in microrems[a] Second quarter	Third quarter	Fourth quarter
81	22.0	35.0	25.8
82	21.6	39.2	25.8
83	19.3	33.9	26.4
84	17.8	28.7	24.0
85	17.8	30.8	24.0
Average	19.7 ± 2.0	33.5 ± 4.0	25.2 ± 1.1

[a]To convert microrems per hour to microsieverts per hour, multiply microrems per hour by 0.01.

Table 8. Results of TLD readings for SRWDA No. 1, 1980

TLD no.	Dose equivalent rate measured in microrems per hour[a] First quarter	Second quarter	Third quarter	Fourth quarter
81	29.6		34.3	33.2
82	32.4		39.1	30.7
83	29.6		31.9	30.7
84	26.8		25.7	27.1
85	24.6		29.5	33.9
Average	28.6 ± 2.99		32.1 ± 5.03	31.1 ± 2.67

[a]To convert microrems per hour to microsieverts per hour, multiply microrems per hour by 0.01.
[b]No data available.

Table 9. Results of TLD readings for SRWDA No. 2, 1979

TLD no.	Dose equivalent rate measured in microrems per hour[a] Second quarter	Third quarter	Fourth quarter
1	12.9	25.1	19.2
2	14.8	18.3	17.4
3	11.4	13.6	12.6
4	9.8	16.2	13.8
5	9.1	15.7	13.2
Average	11.6 ± 2.3	17.8 ± 4.4	15.2 ± 2.9

[a]To convert microrems per hour to microsieverts per hour, multiply microrems per hour by 0.01.

Table 10. Results of TLD readings for SRWDA No. 2, 1980

Dose equivalent rate measured in microrems per hour[a]

TLD no.	First quarter	Second quarter[b]	Third quarter	Fourth quarter
1	21.2		16.2	14.6
2	20.1		17.1	16.8
3	14.5		11.4	11.4
4	15.1		13.8	13.2
5	15.6		15.2	13.9
Average	17.3 ± 3.1		14.7 ± 2.2	13.9 ± 2.0

[a]To convert microrems per hour to microsieverts per hour, multiply microrems per hour by 0.01.
[b]No data available.

Table 11. Results of TLD readings for the construction landfill, 1979

Dose equivalent rate measured in microrems per hour[a]

TLD no.	Second quarter	Third quarter	Fourth quarter
86	9.1	13.6	10.8
87	12.1	13.1	10.8
88	14.0	19.8	16.8
89	10.2	16.7	12.6
90	11.7	15.7	13.2
91	10.2	15.1	10.8
92	9.8	13.1	11.4
93	10.6	12.5	10.8
94	10.6	16.2	11.4
95	9.1	13.1	10.2
96	12.0	19.8	18.0
97	11.0	15.7	11.9
98	9.1	14.6	10.2
99	9.8	14.1	10.8
100	11.4	13.6	10.8
Average	10.7 ± 1.4	15.1 ± 2.3	12.0 ± 2.4

[a]To convert microrems per hour to microsieverts per hour, multiply microrems per hour by 0.01.

Table 12. Results of TLD readings for the construction landfill, 1980

Dose equivalent rate measured in microrems per hour[a]

TLD no.	First quarter	Second quarter[b]	Third quarter	Fourth quarter
86	11.2		10.5	10.4
87	11.7		11.4	9.6
88	17.3		15.7	17.9
89	16.8		12.9	12.1
90	14.5		13.8	11.8
91	17.9		11.0	11.8
92	14.0		10.0	10.3
93	12.9		11.9	10.3
94	13.4		12.4	11.4
95	13.4		11.0	9.3
96	11.2		20.5	16.8
97	20.7		12.4	12.1
98	12.3		10.0	11.1
99	12.3		11.9	10.7
100	12.9		11.9	13.9
Average	14.2 ± 2.78		12.5 ± 2.66	12.0 ± 2.47

[a]To convert microrems per hour to microsieverts per hour, multiply microrems per hour by 0.01.

[b]No data available.

Table 13. **Results of TLD readings for SRWDA No. 4, 1979**

	Dose equivalent rate measured in microrems per hour[a]		
TLD no.	Second quarter	Third quarter	Fourth quarter
6	45.4	61.6	
7	26.1	36.0	36.6
8	22.3	28.7	28.2
9	13.6	17.8	61.2
10	12.1	17.2	17.0
11	16.3	22.5	22.2
12	11.7	15.7	17.4
13	14.8	19.8	22.2
14	22.3	29.2	27.0
15	41.6	57.4	53.4
16	175.2	202.5	208.6
17	39.7	47.5	49.2
18	29.1	31.3	67.1
19	80.6	112.8	89.3
20	15.1	20.9	45.6
Average	37.7 ± 42.2	48.0 ± 49.7	50.5 ± 48.8

[a]To convert microrems per hour to microsieverts per hour, multiply microrems per hour by 0.01.

Table 14. Results of TLD readings for SRWDA No. 4, 1980

Dose equivalent rate measured in microrems per hour[a]

TLD no.	First quarter	Second quarter[b]	Third quarter	Fourth quarter
6	73.7		62.9	53.5
7	41.9		36.7	32.1
8	30.2		30.0	28.2
9	21.2		16.7	16.0
10	19.0		19.1	14.3
11	24.0		17.1	20.3
12	20.1		16.7	14.6
13	25.7		19.1	18.2
14	30.7		29.1	25.7
15	62.6		52.9	59.2
16	242.4		215.2	232.1
17	59.2		46.7	50.0
18	69.8		50.0	48.2
19	99.4		168.6	89.6
20	36.9		20.0	15.0
Average	57.1 ± 56.5		53.4 ± 58.8	47.8 ± 55.4

[a]To convert microrems per hour to microsieverts per hour, multiply microrems per hour by 0.01.

[b]No data available.

Table 15. Results of TLD readings for SRWDA No. 5, 1979

TLD no.	Dose equivalent rate measured in microrems per hour[a] Second quarter	Third quarter	Fourth quarter
21	15.1	21.9	25.8
22	12.5	18.8	21.6
23	11.4		16.2
24	10.2	17.8	16.2
25	13.3	18.8	17.4
26	12.1	18.3	19.2
27	11.4	17.8	27.0
28	11.4	18.3	17.0
29	15.5	18.3	14.4
30	11.4	16.2	17.0
31	10.2	16.2	15.6
32	11.4	15.7	15.6
33	11.0	15.7	15.6
34	12.5	19.3	18.0
35	12.5	18.8	19.8
36	11.7	15.1	18.6
37	12.1	17.2	15.6
38	10.2	14.6	15.6
39	11.0	14.6	15.6
40	12.1	19.3	17.0
41	14.8	21.9	18.0
42	8.7	15.1	12.0
43	9.8	15.7	15.0
44	11.7	17.2	12.6
45	11.0	16.2	15.6
46	11.4	15.7	15.0
47	12.9	17.8	15.0
48	9.1	14.6	14.4
49	10.2	14.6	12.6
50	14.4	17.8	15.0
Average	11.8 ± 1.6	17.2 ± 2.0	16.8 ± 3.3

[a] To convert microrems per hour to microsieverts per hour, multiply microrems per hour by 0.01.

Table 16. Results of TLD readings for SRWDA No. 5, 1980

TLD no.	Dose equivalent rate measured in microrems per hour[a] First quarter	Second quarter[b]	Third quarter	Fourth quarter
21	31.3		17.1	19.3
22	26.3		20.5	19.3
23	20.7		18.6	15.0
24	19.0		14.3	15.0
25	21.8		14.8	16.4
26	25.1		15.2	15.4
27	21.8		15.7	18.6
28	19.6		14.3	16.8
29	17.9		15.2	17.1
30	30.7		13.3	16.8
31	18.4		14.3	27.5
32	18.4		12.9	16.4
33	19.0		13.3	19.3
34	21.2		16.2	16.4
35	20.7		16.7	18.2
36	20.1		12.9	15.0
37	17.3		14.3	16.8
38	19.0		12.9	14.3
39	18.4		13.8	15.4
40	21.2		16.7	17.1
41	20.7		19.5	38.9
42	27.9		11.4	17.5
43	16.8		14.8	14.6
44	15.1		11.4	16.4
45	17.3		13.3	14.3
46	16.2		13.8	31.8
47	21.2		16.7	17.1
48	16.8		12.4	12.5
49	16.2		13.3	13.2
50	16.2		14.3	15.7
Average	20.4 ± 4.13		14.8 ± 2.20	17.9 ± 5.5

[a]To convert microrems per hour to microsieverts per hour, multiply microrems per hour by 0.01.

[b]No data available.

Table 17. Results of TLD readings for SRWDA No. 6, 1979

Dose equivalent rate measured in microrems per hour[a]

TLD no.	Second quarter	Third quarter	Fourth quarter
51	24.2	19.3	31.2
52	15.1	20.4	14.4
53	8.7	12.0	10.8
54	10.2	12.5	12.8
55	14.4	18.3	15.0
56	lost	14.6	15.0
57	14.0	21.4	15.6
58	lost	22.5	19.8
59	19.3	25.6	24.6
60	13.6	20.4	18.0
61	9.5	16.7	12.6
62	10.2	25.1	12.0
63	9.5	16.2	12.0
64	8.7	15.7	10.8
65	9.8	15.1	12.0
66	9.5	14.6	11.4
67	9.1	14.6	13.2
68	10.6	17.2	17.4
69	13.3	20.9	18.6
70	23.8	42.3	42.0
71	27.6	42.3	62.4
72	15.9		24.0
73	12.5	17.8	18.0
74	9.5	16.7	12.6
75	10.2		13.2
76	9.8	15.1	12.6
77	10.6	16.2	18.0
78	23.5	14.6	19.2
79	12.5	19.3	25.8
80	19.7	32.4	39.6
Average	13.4 ± 4.8	20.0 ± 7.7	19.5 ± 11.4

[a]To convert microrems per hour to microsieverts per hour, multiply microrems per hour by 0.01.

Table 18. Results of TLD readings for SRWDA No. 6, 1980

Dose equivalent rate measured in microrems per hour[a]

TLD no.	First quarter	Second quarter[b]	Third quarter	Fourth quarter
51	29.1		59.5	53.2
52	16.2		17.1	18.6
53	12.9		8.6	10.7
54	13.4		13.3	11.8
55	18.4			27.8
56	16.8		23.8	
57	19.6		15.2	48.9
58	24.6		20.0	22.5
59	35.8		41.4	23.2
60			22.9	24.3
61			27.1	18.2
62	14.5		14.3	14.3
63	14.0		12.4	12.9
64	15.1		13.8	13.6
65	14.0		15.2	12.5
66	14.0		14.8	13.6
67	14.0		14.8	14.6
68	21.8		30.0	26.4
69	27.4		30.0	33.6
70	69.3		78.6	99.3
71	128.5		193.8	226.1
72	42.5		56.2	58.9
73	34.1		42.9	23.2
74	19.6		23.3	26.4
75	19.0		18.1	18.6
76	14.5		11.9	12.8
77	31.8		35.7	36.8
78	38.0		45.2	57.5
79	53.1		77.1	67.8
80	77.1		116.2	110.4
Average	30.3 ± 25.5		37.7 ± 39.0	39.3 ± 44.1

[a]To convert microrems per hour to microsieverts per hour, multiply microrems per hour by 0.01.

[b]No data available.

Table 19. Average TLD results for the two-year period

Dose equivalent rate measured in microrems per hour[a]

Waste disposal area	1979 Second quarter	1979 Third quarter	1979 Fourth quarter	1980 First quarter	1980 Third quarter	1980 Fourth quarter	Average
1	19.7	33.5	25.2	28.6	32.1	31.1	28.4 ± 5.2
2	11.6	17.8	15.2	17.3	14.7	13.9	15.1 ± 2.3
Construction landfill	10.7	15.1	12.0	14.2	12.5	12.0	12.8 ± 1.6
4	37.7	48.0	50.5	57.1	53.4	47.8	49.1 ± 6.6
5	11.8	17.2	16.8	20.4	14.8	17.9	16.5 ± 2.9
6	13.4	20.0	19.5	30.3	37.7	39.3	26.7 ± 10.6

[a]To convert microrems per hour to microsieverts per hour, multiply microrems per hour by 0.01.

process is apparently accelerating, possibly because of the unseasonably heavy rains and a poor drainage system. However, SRWDA No. 1 indicated no leaching during the period of this study. Currently, SRWDA's Nos. 5 and 6 are operating. The exposure rates at these sites are slightly higher than those from the natural background.

There are some higher-than-normal exposure rates at certain monitoring locations at SRWDA's Nos. 4 and 6. At SRWDA No. 4 these locations are 16, 19, 15, and 17 (see Fig. 8), in order of decreasing exposure rate. These higher exposure rates are possibly attributable to floodplains. All of the above-mentioned locations are situated near the rainwater runoff passages and are on the downslope from the other locations. At SRWDA No. 6, locations 70, 71, and 80 show higher-than-normal exposure rates. The results of a survey in which portable gamma survey instruments were used indicate that the elevated readings are primarily due to the presence of White Oak Lake. The increase in exposure rates, starting with the fourth quarter of 1979, coincides with the lowering of White Oak Lake during the same period.

Elevated exposure rates at different locations in all the SRWDA's could be at least partly the result of dosimeter placement. Some dosimeters may have been placed right above a waste trench and would, therefore, indicate a higher exposure rate. No attempt was made to avoid trenches or other possible gamma sources in choosing the TLD survey locations.

No clear trends of exposure rates with time were found that could be attributed to radioactivity migration. It is suggested that a detailed and comprehensive study be initiated before any remedial or corrective action is taken. This new study should take into account the location of the burial trenches and the locations at which the previous abnormal readings were observed. Portable gamma survey meter readings should be taken to determine the sites of elevated radiation levels in suspected seep areas. Care should be taken to minimize the effects of gamma radiation from White Oak Lake or of other possible interferences. The results of the study should provide helpful data for planning better water drainage systems at SRWDA's Nos. 4 and 6, and these sites should be given the highest priority for future study.

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